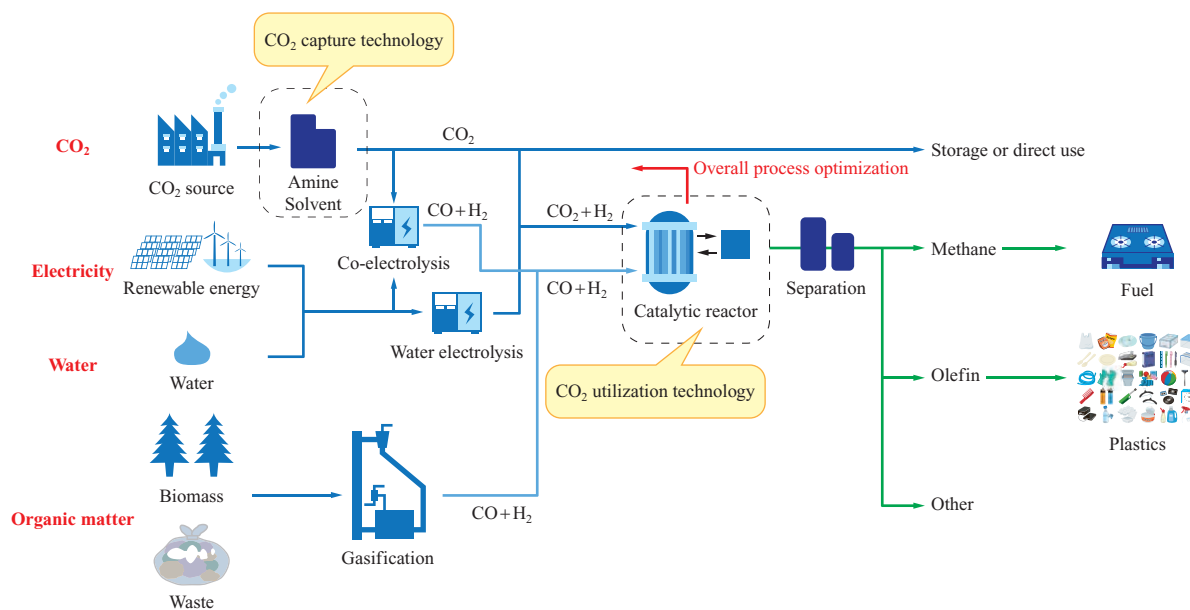


Realization of a Carbon Recycling Society through Effective Use of CO₂

Development of cost-effective CO₂ capture technology and CO₂ utilization technology

At an Australian power plant, IHI's unique solvent and plant technology have enabled over 5 000 hours of stable CO₂ recovery with a capture ratio of 90% or more, contributing to realizing a carbon recycling society together with conversion catalyst development.

ENDO Takumi
Business Development Department,
Resources, Energy & Environment Business Area,
IHI Corporation



CO₂ capture and utilization process flow

Various ways to reduce CO₂ emissions

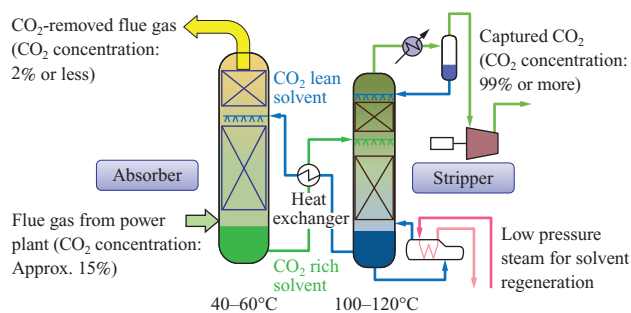
As is commonly known, global warming is an urgent global issue, and there is a strong demand to reduce carbon dioxide (CO₂) emissions by every possible means.

There are various ways of reducing CO₂ emissions, such as enhancing energy conversion efficiency, implementing renewable energy, and shifting to carbon-neutral fuels. Particularly, in the plant engineering field, there are high

expectations for CO₂ capture technology and CO₂ utilization technology for effective use of recovered CO₂. It is because the application of these technologies for existing facilities allows the facilities to continue to be used. This article introduces the technologies the IHI group has been developing to capture CO₂ with the chemical absorption technique and to convert the recovered CO₂ to valuable products, such as fuels and raw materials.

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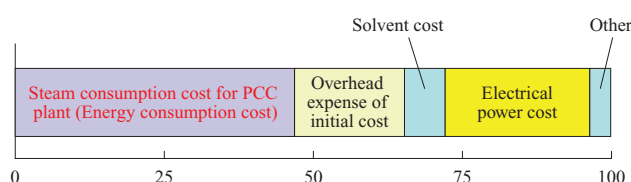
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Principle of CO₂ capture based on the chemical absorption process

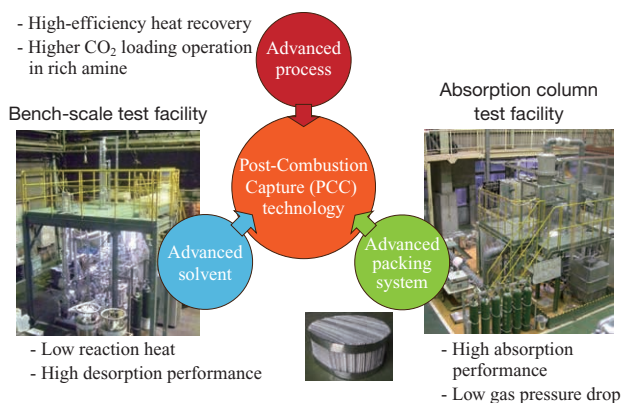
CO₂ capture technology

There are various CO₂ capture technologies. Among them, the one using a chemical absorption technique is an excellent technology that uses chemical absorption and desorption reactions with an alkaline solution, such as an amine solution, as a solvent to capture CO₂ mainly from flue gases. Specifically, as shown in the figure above, a flue gas from a power plant is introduced into an absorber, where the gas is allowed to come in contact with a solvent containing little CO₂ (i.e. lean solution) and CO₂ in the flue gas is absorbed selectively by the solvent. Once the solvent has absorbed a lot of CO₂ (i.e. rich solution), it is sent to a stripper, where the CO₂ absorbed by the solvent is separated as a gas by heating the solvent, followed by cooling and compression process, thereby achieving the recovery of CO₂ with a high



(Note) PCC : Post-Combustion Capture
(Source) FY2002 NEDO survey report (02004342, and 02004343)

The constitution of the CO₂ capture cost (example) (%)



IHI's key technologies of PCC for energy saving

purity of 99% or more. After the CO₂ has been stripped, the lean solution, whose CO₂ absorbing capability has been recovered, is sent to the absorber again, so the solvent can be circulated and reused. In these capture processes, however, the cost for the energy for heating the solvent in the stripper (i.e. regeneration energy) accounts for about half of the total cost, causing a significant economic impact. Therefore finding better ways to reduce this regeneration energy consumption is challenging yet crucial when reducing CO₂ emissions with a chemical absorption technique, and the IHI group has been working on this very problem.

Reducing the regeneration energy

The IHI group has been studying the parameters that greatly affect the regeneration energy, and focusing on the three technical developments in the table below.

First, these individual element technologies that we developed by ourselves were tested by using the bench-scale test facility and absorption column test facility installed on the premises of IHI's Yokohama Works. The obtained results were analyzed and we got a clear view of achievement of the target regeneration energy.

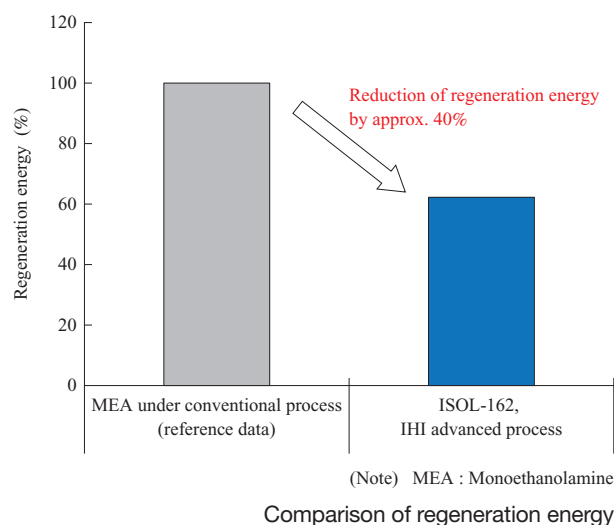
Next, the results obtained with these small test facilities were embodied in the chemical absorption pilot plant

Development	Parameter	For energy saving
① Development of processes using heat effectively	Absorbing solvent temperature	Effective use of high-temperature absorbing solvent
② Development of solvent with low reaction heat	Stripper operation temperature	Decrease of the temperature
③ Development of packing system with high absorption efficiency	Amount of recirculating solvent	Decrease of the circulation amount

Developments for saving the regeneration energy



20 t-CO₂/d pilot plant



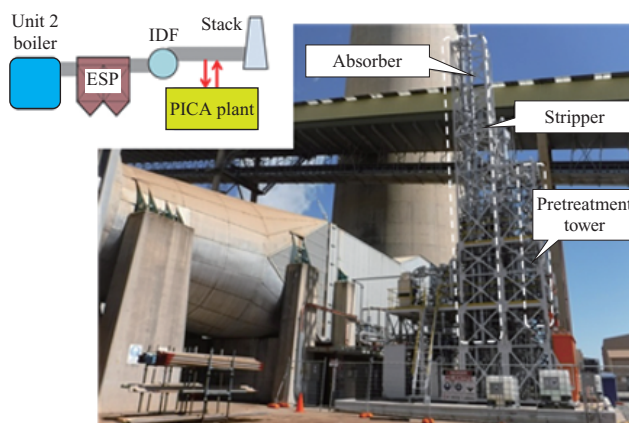
installed on the premises of IHI's Aioi Works (hereinafter, the pilot plant) to evaluate and improve the overall performance. This pilot plant is a demonstration test facility that separates and recovers CO₂ from the flue gas of a coal-fired boiler with a heat output of 20 MW to simulate use in an actual facility. This pilot plant has the highest level of CO₂ recovery capability among Japanese demonstration facilities at 20 t-CO₂/d. In an effort to reduce the regeneration energy consumption, a series of tests was conducted with support from the New Energy and Industrial Technology Development Organization (NEDO) under the "Strategic Innovation Program for Energy Conservation Technologies."

With this pilot plant, a series of tests was conducted for the three technological developments mentioned above, which demonstrated that compared to conventional solvents, the regeneration energy consumption could be reduced by approximately 40% with a CO₂ absorption efficiency of 90% or more.

Robustness and operability

Based on the results of these developments, long-term demonstrative operation was conducted by using flue gas from an actual thermal power plant to verify the robustness of IHI-developed solvent (ISOL-162) and the operability of IHI's unique advanced processes. This demonstration test was conducted jointly with AGL Loy Yang Pty Ltd and CSIRO (Commonwealth Scientific and Industrial Research Organisation), which is the largest research institution in Australia, with support from BCIA (Brown Coal Innovation Australia; current ACI [Australian Carbon Innovation]). AGL Loy Yang Pty Ltd is the owner of the Loy Yang A power plant, which supplies approximately 30% of the electricity in Victoria, Australia.

In this demonstration, CO₂ was recovered from the flue gas of an actual thermal power plant over a total of more than 5 000 hours by using the ISOL-162. The planned CO₂ recovery efficiency of 90% was achieved and it was



Demonstration test facility at Loy Yang A power plant in Australia

demonstrated that the ISOL-162 is robust enough to withstand prolonged operation.

In addition, while the operation of the CO₂ capture facilities is monitored by operators during the daytime on weekdays, it was also demonstrated that the solvent and processes are stable enough to operate these facilities without operators at night and during holidays with careful prior risk assessment and remote monitoring.

In March 2019, a total operation time of 13 000 hours was achieved (including the time with other solvents), which demonstrates that the pilot plant has high efficiency and excellent stability. The plant is still in operation (as of May 2019). These achievements demonstrate that this cost-effective CO₂ capture system is ready to be made available to customers.

CO₂ utilization technology

The following is a proposal on ways to use the recovered CO₂ to reduce CO₂ emissions.

Underground CO₂ storage is one way to reduce CO₂ emissions in large scale, and discussions are being held about the geographical issues and cost burden related to it. At the same time, there is a demand for "carbon recycling technologies," by which CO₂ is converted into valuable products and returned to market, although they only bring about small reductions in CO₂ emissions. The IHI group is developing technologies to convert recovered CO₂ into valuable products, such as fuels and chemical raw materials.

The IHI group has been developing a catalyst technology to turn syngas (H₂ and CO), which is obtained when coal or biomass is gasified, into methane. With this technology, the CO₂ contained in flue gas is allowed to react with H₂ obtained from renewable energy, such as solar PV (PhotoVoltaic) power, in the presence of a catalyst to produce a methane gas fuel. This technology makes it possible to convert CO₂ captured from a plant where fossil fuel is consumed (e.g., thermal power plant, ironworks) into methane gas.

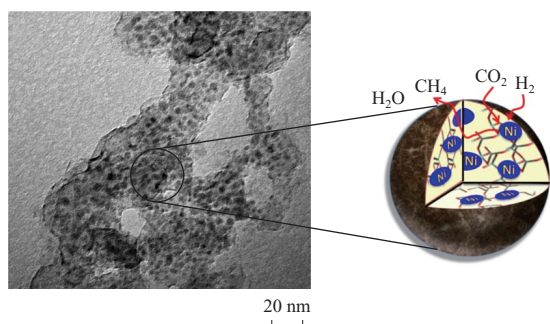


Photo and schematic diagram of IHI-ICES catalyst

Introducing this converted methane gas into an existing city gas pipeline makes it possible to use the methane gas widely with, for example, household stove burners, without modifying or replacing existing infrastructure facilities.

To accelerate this research and development, the IHI group began joint research with ICES (Institute of Chemical and Engineering Sciences), which is a chemical engineering institute under the umbrella of the Singapore's A*STAR, and developed a more active and longer lasting catalyst (see the figure above, from Dispersed and high loading Ni catalyst stabilized in porous SiO₂ matrix for substituted natural gas production (H. Kamata et al., *Catalysis Today*, Vol. 299, 2018)). For more detailed information, refer to Methanation Catalyst (US 9 802 872). To evaluate this catalyst, laboratory-scale test facilities (see the figure at the bottom) were

installed in Singapore and IHI's Yokohama Works for demonstration testing scheduled in FY2020.

In addition, the IHI group is developing a catalyst for producing olefin, which is used as a raw material mainly for plastic (polymer compound consisting mainly of ethylene and propylene), as a high-value-added product from CO₂. Moreover, the IHI group is working to optimize the overall processes, including chemical reactions for such value addition and relevant functions.

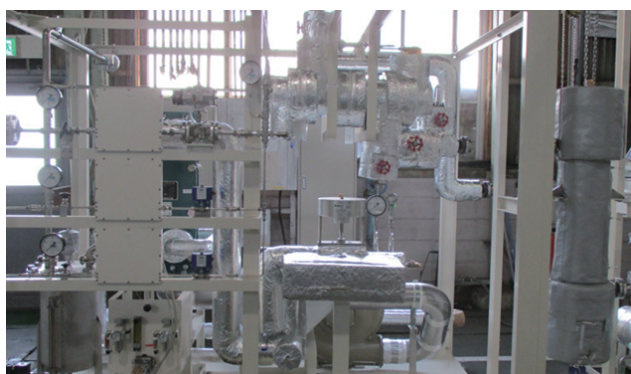
At the same time, the IHI group is conducting research to establish a system for producing H₂ efficiently from renewable energy as it is necessary to add value to CO₂, and is planning to conduct demonstrative research to produce fuels and chemical raw materials from CO₂ in an integrated manner by using H₂ generated from solar PV power.

For the realization of a carbon recycling society (future development)

For the purpose of CO₂ emissions reduction, the IHI group considers carbon recycling as an important part of overall emission reduction pathway and is aiming to introduce into society the technologies to recover CO₂ efficiently and convert the recovered CO₂ into fuels and raw materials containing carbon with hydrogen and heat derived from renewable energy. The IHI group will be offering various solutions to reduce CO₂ emissions in a wide variety of customers' situations, thereby contributing to realizing a decarbonized society.



Demonstration facility in Singapore



Laboratory-scale catalyst performance test facility

Inquiries:

Business Development Department,
Resources, Energy & Environment Business Area,
IHI Corporation
Phone: +81-3-6204-7506
<https://www.ihico.jp/en/>